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# Stress qualifications for standard and nonstandard valves in piping systems

Various types of valves are used in refineries, petrochemical plants, fertilizer plants and utilities. As a part of a low- or high-pressure/temperature piping system, these valves are subjected to fluid pressure/temperature, as well as to external loads from a connected piping system. A design engineer should perform a stress analysis of stress-critical piping systems for qualifying the piping system (including fittings, valves, etc.), as per applicable design codes.

An approach is defined here to highlight the requirements for stress qualification of the standard pressure-temperature (P-T) rating for nonstandard valves, either individually or as part of piping system in which they are installed.

**Importance of valve rating.** In a piping system, piping components like valves, flanges and other elements are essential for the safe and reliable operation of the plant, but they are also much heavier and/or stiffer than the pipe and pipe fittings. A stress analysis of these critical piping systems is performed with the use of piping stress analysis software. Such software considers the stiffer components as rigid elements and does not calculate the stress on these elements.

When the piping stress analysis software computes the stiffness matrix and solves for loads, the rigid valve will transfer the load from one side of the pipe to the other. In this analysis, a rigid-body element does not deform or show induced stress values or failures. However, if the piping stress analysis software does not consider the imposed piping load and moments on valves for stress qualification, and if it does not predict the stress failure of the rigid elements, then what is the basis for qualifying the total piping system? The basis must include standard P-T rating valves for different load cases including sustained, thermal and others.

Standard P-T rating valves must be qualified with the use of finite element analysis (FEA). The structural strength of valve bodies and flanges must be analyzed under the composite action of fluid pressure and external piping loads. Also, some piping systems contain nonstandard valves, such as the slide valve in an FCC unit. What approach should be followed for qualifying these valves?

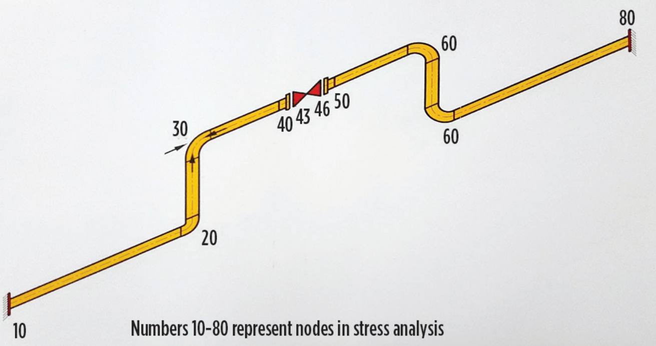


**FIG. 1.** High-temperature/high-pressure piping system with vertical loop.

**TABLE 1. Piping details and process design parameters**

| | |
|---|---|
| Size | 14 in. |
| Means of compliance | ASTM A335 P22 (seamless) |
| Pressure rating | 1,500 lb |
| Operating pressure, $P_1$ | 42.5 kg/cm$^2$g |
| Design pressure, $P_2$ | 47.3 Kg/cm$^2$g |
| Hydrotest pressure, HP | 138.4 Kg/cm$^2$g |
| Operating temperature, $T_1$ | 400°C |
| Design temperature, $T_2$ | 515°C |

**Case study for stress qualification of standard P-T valves.** A hypothetical high-temperature and high-pressure piping system configuration with a vertical loop (**FIG. 1**) is considered for the case study. The important parameters and process design conditions are given in **TABLE 1.** This piping configuration, along with the valve assembly, is analyzed by the piping stress analysis software for different load cases.

Analysis results for this case show that piping system stresses are higher in both the expansion and sustained conditions; however, these stresses are within the ASME B31 code limits (**TABLE 2** and **TABLE 3**). The code expansion stress ratio and the code sustained stress ratio represent the ratios between generated and allowable stresses. W + P + T and W + P represents the operating and sustained load cases, respectively, where W, P and T are the operating weight, pressure and temperature of the piping system for the respective operating conditions.

**TABLE 5** shows that flange leakage calculations based on the generated piping moment are performed, and stresses are

within the code limit. TABLE 2 and TABLE 3 results also show that calculated stresses for valves are within the code limit. From TABLE 4, it is evident that piping stress analysis software does not calculate stresses at rigid components, such as valves. The expansion stress at valve nodes 40, 43 and 46 are zero.

Since the values of stresses at the valve nodes are zero, how can the generated stress on the standard P-T rating for the valve in the case study be determined to fall within the code limits? Must the same valve be qualified independently by another method? From the outlined analysis, it is evident that the piping configuration—with the exception of the valve—has stresses within the code limit. An analytical approach for the independent qualification of the valve is detailed in the next section.

**Standard P-T rating valve stress qualification.** For the individual qualification of a valve, FEA of the valve body structure must be performed to analyze the valve under the conditions of pressure and temperature rating envelope, along with the maximum possible imposed external loads from the attached piping system.

When performing FEA analysis for the valve body structure, the judgement to be made of external loading from the piping system for optimizing the valve design can be obtained using ASME Boiler and Pressure Vessel Code (BPVC) Section 3: NC 3658.3 for dynamic loading, with some safety margins. An example of such a judgment is the external moment of the piping system = yield strength (YP) × the maximum possible section modulus of the connected piping (Z) or the value of the external moment for a flanged valve. The external loading value derivation must be performed judiciously, as too much leeway can result in an uneconomical valve design.

Valve manufacturers perform FEA analysis of these valves based on type, size, material and P-T rating for design qualification prior to valve production, considering the maximum load scenario as per valve P-T rating conditions. As allowable stresses of valve material (casting or forging) and section modulus are usually relatively higher than the connected piping, the same design valve that has already been qualified by the manufacturer does not need to be analyzed or qualified for each new piping system installation.

Manufacturers can also use an experimental method for the qualification of standard P-T rating valves in place of FEA analysis. In this method, the manufacturer applies actual internal pressure and external forces and moments in a properly designed test bench. The test bench loading can be applied repeatedly if fatigue effect must also be evaluated.

**Nonstandard design (special valve) stress qualification.** Critical/special piping systems in which nonstandard valves must be installed (e.g., valves used in FCC plant piping, such as catalyst slide valves, fuel gas slide valves, etc.) require the manufacturer to perform FEA for qualification, considering the defined pressure and temperature envelope and the maximum possible imposed external loads from the attached piping. This analysis is required for several reasons:

1. In piping systems for such applications, the actual piping load may be higher than the manufacturer's standard

**TABLE 2.** Maximum expansion stress in piping system

| | | |
|---|---|---|
| Maximum expansion stress load case $(W + P_2 + T_2) - (W + P_1)$ | | |
| Piping code: ASME B31.3—January 31, 2017 | | |
| Highest stresses, N/mm² | | |
| Code expansion stress ratio, % | 81.7 | At node 58 |
| Code stresses | 196.8 | Allowable stresses: 240.8 |
| Axial stresses | 5.1 | At node 40 |
| Bending stresses | 191.7 | At node 58 |
| Torsion stresses | 0 | At node 59 |
| Hoop stresses | 0 | At node 18 |
| Max. stress intensity | 203.2 | At node 58 |
| Result: Code compliance evaluation passed | | |

**TABLE 3.** Maximum sustained stress in piping system

| | | |
|---|---|---|
| Sustained load case at operating pressure $(W + P_1)$ | | |
| Sustained load case at design pressure $(W + P_2)$ | | |
| Piping code: ASME B31.3—January 31, 2017 | | |
| Highest stresses, N/mm² | | |
| Code sustained stress ratio, % | 74.9 | $W + P_2$ at node 80 |
| Code stresses | 53.2 | Allowable stresses: 71 |
| Axial stresses | 8.9 | $W + P_2$ at node 20 |
| Bending stresses | 44.6 | $W + P_1$ at node 80 |
| Torsion stresses | 0 | $W + P_1$ at node 70 |
| Hoop stresses | 19.5 | $W + P_2$ at node 18 |
| Max. stress intensity | 53.5 | $W + P_2$ at node 80 |
| Result: Code compliance evaluation passed | | |

**TABLE 5.** Flange leakage calculation at valve flange joint

**Flange ASME BPVC Section 3 NC 3658.3 report**

Operating load case design condition: $W + T_2 + P_2$

| Node | Torsion moment, Nm | Bending moment, Nm | G/C, mm | Flange stress, N/mm² | Allowable pressure/ stress, N/mm² | Ratio, % |
|---|---|---|---|---|---|---|
| 40 | 0 | 327,037 | 635 | 190.28 | 213.25 | 89.23 |
| 43 | 0 | 326,643 | 635 | 190.05 | 213.25 | 89.12 |
| 46 | 0 | 351,777 | 635 | 204.68 | 213.25 | 95.98 |
| 50 | 0 | 364,897 | 635 | 211.96 | 213.25 | 99.4 |

**TABLE 4.** Expansion stresses at valves

| Load case | From node | Code stress, N/mm² | Allowable stress, N/mm² | To node | Code stress, N/mm² | Allowable stress, N/mm² | Piping code |
|---|---|---|---|---|---|---|---|
| Expansion | 40 | 0 | 0 | 43 | 0 | 0 | ASME B31.3 |
| Expansion | 43 | 0 | 0 | 46 | 0 | 0 | ASME B31.3 |
| Expansion | 46 | 0 | 0 | 50 | 0 | 0 | ASME B31.3 |

guidelines due to limited piping flexibility and the requirements of the standard layout.

2. Strength and section modulus for nonstandard valves may be less in comparison to standard valves, as dedicated design standards are not available for nonstandard valves. Established design standards have a higher safety factor that ensures sufficient strength and section modulus.

A stress engineer should communicate with the manufacturer and provide/verify the loads to be used for valve design.

Two main types of loads act on the valve body: thermal load (temperature) and structural load (pressure). In **FIG. 2,** point Z1 shows the outer part of the valve exposed to the atmosphere, Z2 shows the inner side of the valve that comes into contact with the fluid domain, and Z3 shows the inner side of the valve subjected to pressure load.

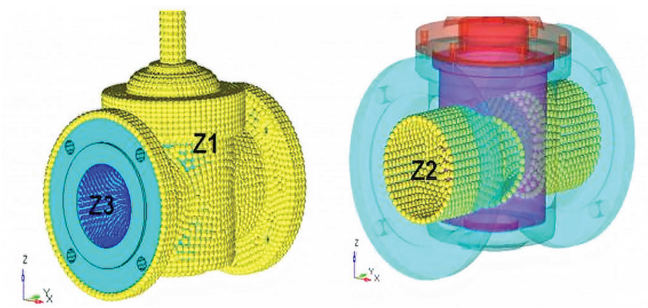


**FIG. 2.** Valve and loads.

When a nonstandard valve is installed in a piping system, the pressure of the internal medium, the bending or torsion moment (M), as well as the external pressure loads ($F_1$) and external tension loads ($F_2$), are applied on a case-by-case basis.

An FEA analysis of the valve can be performed assuming that M, $F_1$ and $F_2$ are applied simultaneously, along with the internal medium pressure of the valve. The composite action of an external force and the internal medium pressure will be considered in the analysis of the structural strength of the valve body.

**Recommendations.** Standard P-T rating valves installed in stress-critical piping systems can be automatically qualified if the connected piping is qualified with a software-aided stress analysis. Individual stress qualification by another analysis (e.g., FEA) is not required for these valves for each piping system.

In critical/special piping systems in which nonstandard valves are to be installed, FEA analysis of valves is required. A design engineer should communicate with the manufacturer and provide/verify the loads to be used for valve design to ensure safe and reliable plant operation. HP

**MRINMOY GHOSH CHOUDHURY** is an Engineering Professional with extensive experience in process plant engineering from concept to commissioning, with special emphasis on piping and plant engineering. He has contributed a number of papers to reputed engineering journals. He has worked for Reliance Engineering, Toyo Engineering India, Chemtex Engineering India, Engineers India Ltd. and DCL.